Active and Passive Microring Resonator Filter Applications on GaInAsP/InP

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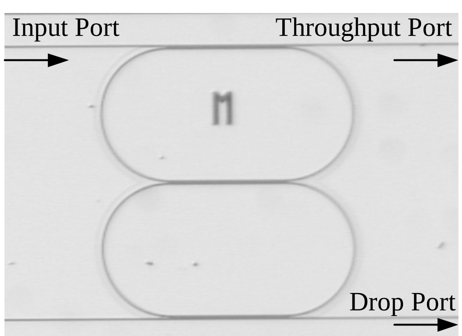
1. Introduction

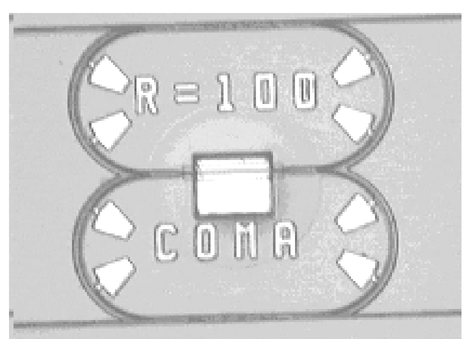
Active and passive ring resonator devices are promising candidates for wavelength filtering, routing, switching, modulation, and multiplexing/demultiplexing applications. Ring resonators do not require facets or gratings for optical feedback and are particularly suited for monolithic integration with other components. The passband shape of ring resonator filters can be custom designed by the use of multiple coupled resonators. The filter characteristic (steep roll-off, flat top and high contrast > 20 dB) depends on the energy flow in the resonators which defines the desired filter shape. Therefore it is important to achieve smooth sidewalls for low waveguide losses, deep etched curvatures for low bending losses and precise waveguide dimensions for power splitting. Steeper roll-off and out-of-band rejection requires cascaded microring resonators. The energy level can be additionally controlled by the implementation of gain sections into the ring resonator. The characteristic response of designed, manufactured and simulated microring resonator filters with codirectional couplers, active sections and multimode interference (MMI) couplers, are presented.

2. Design and fabrication

We investigated and compared different ring resonator arrangements for a channel spacing of 50 GHz and 100 GHz. The first step was to fabricate passive ring resonators with negligible bending losses, minimum sidewall roughness and low insertion losses. The devices in Fig. 1a consist of: InP substrate, GaInAsP (λ_{gap}=1.06 µm, 0.38 µm), InP etch stop layer (0.020 µm), GaInAsP (λ_{gap}=1.06 µm, 0.84 µm), InP cap (0.2 µm). The design assures both, a monomodal propagation of the light in the waveguide and, due to a good confinement, very low bending losses. Additionally, the waveguide was etched down on the outer side of the waveguide in the curvatures. The waveguide width is 1.8 µm. The dimensions of the used compact 3 dB-MMI coupler are 150 µm x 6 µm. The ring resonators were structured by using standard photolithography and a CH_4/H_2 reactive ion etching technique. SiN_x was used as etching mask, which also served as the mask for the deep etching process. In order to reduce the formation of polymers during dry etching and so to minimize the sidewall roughness a small fraction of oxygen was added. The facets of the input and output waveguides have been antireflection coated in order to avoid Fabry-Perot resonances in the straight waveguide section. Examples of fabricated ring resonators are shown in Fig.1.



(a)



(b)

Fig. 1. Photograph of fabricated ring resonators: (a) passive (b) including a gain section

3. Results of passive ring resonators

The double ring resonator (DRR) consisted of two rings with R = 100 µm which were coupled using three MMIs with a length of 150 µm, leading to a FSR of 100 GHz. The experimental results were simulated according to the equation:

$$\frac{I_t}{I_i} = \left|\frac{E_t}{E_i}\right|^2 = D^2 \cdot \left[1 - \frac{\left(1-x^2\right)\cdot\left(1-y^2\right)}{(1-x\cdot y)^2 + 4\cdot x\cdot y\cdot \sin^2\left(\frac{\Phi}{2}\right)}\right]$$

where D is the intensity loss coefficient of the MMI (in the lossless case D = 1), κ is the power coupling coefficient, L is the length of the ring resonator, α is the insertion loss coefficient of the ring. Results are shown in Fig. 3. The ring resonators were characterized using a tapered fiber and an external cavity laser. The insertion loss was 7 dB, which is comparable to those of the single ring resonator (Fig. 2). The contrast of the throughput port and of the drop port are about 3.5 dB and 7.5 dB, respectively. As DRRs comprise 3 MMIs, their total loss prevents the fabrication of high contrast filters, even if the MMI losses correspond to the current state-of-the-art. The expected broadening of the FWHM for the throughput port was measured to be 0.25 nm and 0.4 nm for the drop port.
The performance of passive ring resonators is limited by the inability to control the energy level. Therefore active sections have been implemented in the ring resonator. A standard ridge waveguide structure was used for the gain section, which required an additional epitaxial growth step. To assure precise 100 GHz channel spacing, the resonator´s optical length can be trimmed by, for example, the thermo-optic effect. Results of these devices will be shown at the conference.

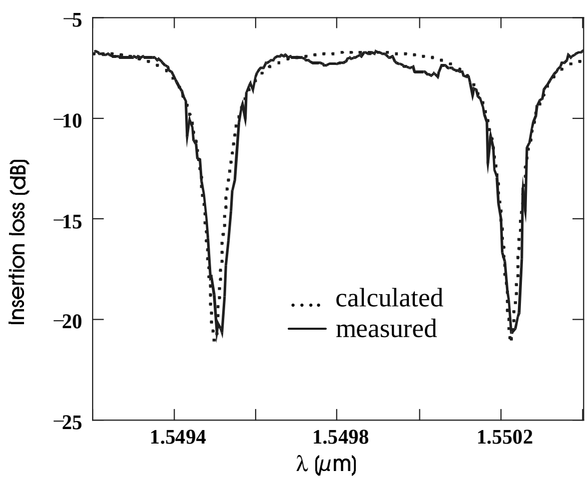


Fig. 2. Result of a passive single ring resonator (R = 100 µm)

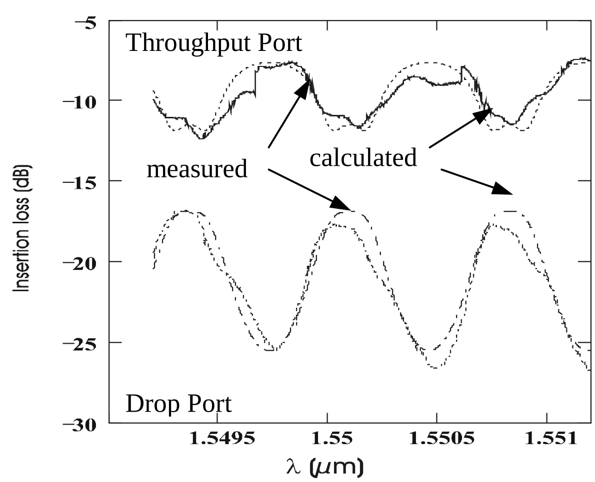


Fig. 3. Result of a passive DRR (R = 100 µm)

4. Summary

Single and double GaInAsP/InP microring resonators with a free spectral range of 50 GHz and 100 GHz were fabricated and characterized. The simulated results coincide very well with experimental values. In varying the gain, the coupling factor, the length and using multiple ring resonators, tailored passband characteristics can be realized. We believe that passive and active (including gain sections) mono and multi ring resonator circuits will become an important component family in optical signal processing applications.

References

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